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Turbulence and anomalous transport in magnetized plasmas: hints from the Reversed Field Pinch configuration

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Coherent structures are observed to emerge from turbulence background in the edge region of plasmas confined in Reversed Field Pinch configurations. These structures have features reminiscent of single vortices in ordinary fluids and their versus of rotation depends on the local shear of the plasma mean velocity.

Plasma fluctuations are commonly recognised as the leading mechanisms ruling particle and energy transport in magnetically confined plasmas for thermonuclear fusion research [1]. This enhanced transport is commonly referred as 'anomalous' transport as it is much larger than the classical one due to collisions. Fluctuations contributing to the transport span a finite range of frequencies usually comprised between the ion cyclotron frequency and frequencies close to those of magnetohydrodynamic (MHD) activity. The time behaviour reveals that both electrostatic and magnetic fluctuations exhibit bursts in a wide range of frequencies including those relevant for transport and this feature seems independent of the specific magnetic configuration, as it is observed in tokamaks [2, 3], stellarators [4] and Reversed Field Pinch (RFP) experiments [5]. An extensive study of the features of these bursts has been carried out in the edge region of RFP experiments RFX and EXTRAP-T2R. In this region it has been found that most of the particle transport is carried by electrostatic fluctuations. It results that the range of fluctuations time scale contributing to the transport are respectively from 5 to 50 µs in RFX and from 2.5 to 20 µs in T2R, while the corresponding toroidal wave length ranges from 0.15 m to 1 m in RFX and from 0.06 m to to 0.6 m in T2R. The statistical analysis of the Probability Distribution Function (PDF) of fluctuations has shown that these bursts belong to the tail of the distribution and that the PDF's tend to develop non gaussian tails at the smaller time scales. These statistical features allowed the bursts to be classified as 'intermittent' events according to the fluid turbulence theory [6].

In both experiments, intermittency was observed in primary electrostatic quantities, such as floating potential and electron density, as well as in derived quantities, like the electrostatic particle flux [5,7]. A study of the bursts observed in the electrostatic particle flux, [5], has evidenced that these events, although representing a small fraction of the signal, carry a large fraction of the particle flux losses up to 50%. The investigation of their time behaviour has shown that

they tend to cluster during magnetic relaxation processes which cyclically takes place in a RFP [8]. This property has lead to the interpretation that they are the effect of some non linear coupling of the internal resonant MHD modes [7]. Sorting out the intermittent events from the turbulent background has allowed the reconstruction of the spatial structure associated to these bursts, to be carried out using different arrays of Langmuir probes inserted in the edge region of the two experiments. In this contribution a review of the salient properties of these structures is presented.

RFX and EXTRAP-T2R experiments are both toroidal devices with aspect ratio R/a = 2m/0.5m and R/a = 1.2m/0.183m respectively. More detailds on the experiments can be recovered from references [9,10]. The results presented refer to data collected in low current discharges, 300 kA and 80 kA respectively, to allow the insertion of the probes. The average electron density was about 1.5 $10^{19}m^{-3}$ in RFX and 1 $10^{19}m^{-3}$ in T2R. The statistical analysis was performed taking into account the most significant time scales for the electrostatic flux, which are peaked around 10 µs and 5 µs respectively for the two experiments.
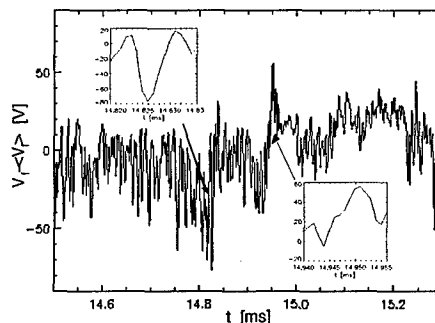

Fig.1 Floating potential fluctuations vs time, the small frames show an expansion of a negative and a positive intermittent event respectively.

Measurements were performed with 1 MHz sampling rate for RFX data and 3 MHz for T2R data; the maximum bandwidth was 400 kHz in both cases

due to the electronic conditioning of signals. In fig.1 is shown a floating potential signal with the characteristics bursts. An expansion of positive and negative bursts is also shown. The bursts correspond to intermittent events identified with the above mentioned technique.

Time correlation indicate that 'frozen turbulence' hypothesis [6] can be applied, so that the bi-dimensional structure can be reconstructed from a radial array of probes and assuming the structure flowing through the probe by a velocity equal to the local electric drift flow. Since in a RFP the magnetic field in the outer region is mainly poloidal and a radial electric field is commonly observed to set up directed inward, the drift velocity is in the toroidal direction with versus opposite to that of the toroidal current.

An example of the radial structure of floating potential for positive and negative intermittent events is shown as a function of time in figure 2. The radial-toroidal structures for the two classes of events are also shown in fig. 2: the corresponding electric field can be deduced and the E×B velocity pattern is derived. In the same fig. 2 the resulting drift velocity is overlaid. The intermittent events are found to correspond to single vortex structures rotating in different versus depending on the sign of the the peak of the floating potential. In RFX the toroidal extension of these structures results in the range $10 \div 15$ cm while their average radial extent, obtained by a weighted averaging, results $3 \div 4$ cm, almost independent of the radial position where the centre of the structure lies. The versus of rotation of the vortices has been found to be strongly dependent on the local mean E×B velocity shear [11].
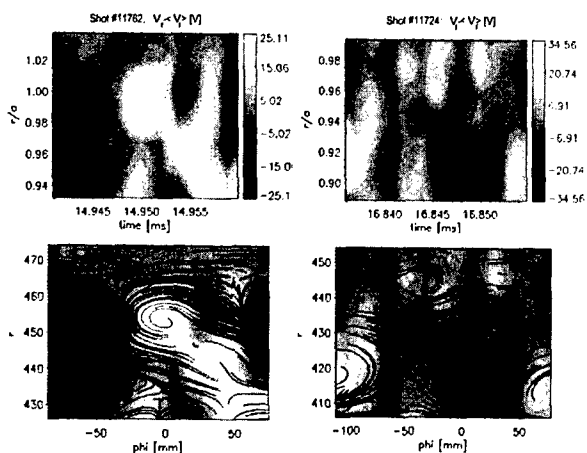

Fig.2 Upper part: radial structure vs time of positive (left) and negative (rigth) floating potential events. Bottom part: deduced radial-toroidal structure for the two classes, the vector plots represent the calculated E×B velocity patterns, data from RFX.

Figure 3 shows the relative fraction of negative and positive peaks vs normalised radial position r/a obtained in the edge of T2R. It can be observed that in the region r/a<1 negative peaks are the majority while the opposite occurs in the outermost region.

In the same figure the radial profile of the mean ExB velocity is also shown. A correlation has been deduced

between the two mentioned regions and the sign of the shear $dv_{E \times B}/dr$. A similar correlation has been observed also in RFX. The relative abundance of vortices with a preferred rotation direction, has suggested that they survives longer when the condition $\omega \cdot \nabla \times \vec{V} > 0$ applies, where $\vec{V}$ is the mean flow velocity, i. e. $v_{E \times B}$ in our approximation, and $\omega = \nabla \times \delta v$ represents the structure vorticity with δv the fluctuating part of flow velocity[11]. The result has a remarkable analogy with vortex dynamics in ordinary sheared fluids and in non neutral plasmas [11]. In particular it has been shown that vortices with versus 'adverse' to the mean vorticity, i.e. with $\omega \cdot \nabla \times \vec{V} < 0$, are fragmented and eventually expelled from the region with unfavourable shear, therefore shortening their average life-time. This result confirms the role of the E×B velocity shear in turbulence regulation as it affects not only the background turbulence but also the emerging structures.

In conclusion intermittent events which emerge from turbulent background as bursts of activity have features reminiscent of single vortices observed in ordinary fluids. These vortices have preferred versus of rotation depending on the local mean E×B shear.
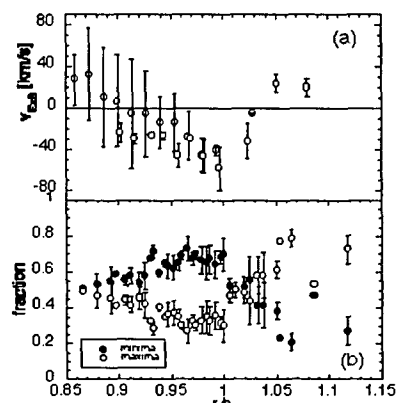

Fig.3 Radial profile of $v_{E \times B}$ measured in the edge of EXTRAP-T2R experiment (a), relative fraction of positive and negative events in the same region (b).

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